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CONTRACT NO: DAMD17-88-C-8053

TITLE: EFFECTS OF HIGH ALTITUDE HYPOXIA ON LUNG AND CHEST WALL
FUNCTION DURING EXERCISE

PRINCIPAL INVESTIGATOR: Jerome A. Dempsey, Ph.D.

CONTRACTING ORGANIZATION: University of Wisconsin
750 University Avenue
Madison, Wisconsin 53706

REPORT DATE: January 27, 1990

TYPE OF REPORT: Midterm Report

PREPARED FOR: U.S. ARMY MEDICAL RESEARCH AND DEVELOPMENT COMMAND
Fort Detrick, Frederick, Maryland 21701-5012

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REPORT DOCUMENTATION PAGE

1a. REPORT SECURITY CLASSIFICATION Unclassified		1b. RESTRICTIVE MARKINGS	
2a. SECURITY CLASSIFICATION AUTHORITY		3. DISTRIBUTION / AVAILABILITY OF REPORT Approved for public release; distribution unlimited	
2b. DECLASSIFICATION/DOWNGRADING SCHEDULE			
4. PERFORMING ORGANIZATION REPORT NUMBER(S)		5. MONITORING ORGANIZATION REPORT NUMBER(S)	
6a. NAME OF PERFORMING ORGANIZATION University of Wisconsin		6b. OFFICE SYMBOL (If applicable)	
6c. ADDRESS (City, State, and ZIP Code) Department of Preventive Medicine 504 N. Walnut Street Madison, WI 53705		7b. ADDRESS (City, State, and ZIP Code)	
8a. NAME OF FUNDING/SPONSORING ORGANIZATION U.S. Army Medical Research & Development Command		8b. OFFICE SYMBOL (If applicable) SGRD-RMI-S	
8c. ADDRESS (City, State, and ZIP Code) Fort Detrick Frederick, Maryland 21701-5012		9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER Contract No. DAMD17-88-C-8053	
11. TITLE (Include Security Classification) Effects of High Altitude Hypoxia on Lung and Chest Wall Function During Exercise		10. SOURCE OF FUNDING NUMBERS	
12. PERSONAL AUTHOR(S) Jerome A. Dempsey, Ph.D.		PROGRAM ELEMENT NO. 62787A	PROJECT NO. 3M1 62787A879
13a. TYPE OF REPORT Midterm		13b. TIME COVERED FROM 6/30/88 TO 12/30/89	
14. DATE OF REPORT (Year, Month, Day) 1990 January 27		15. PAGE COUNT 9	
16. SUPPLEMENTARY NOTATION			
17. COSATI CODES		18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number) Exercise; Cost of Breathing; Limitations to Exercise; Breathing-Mechanics; Respiratory Muscles; RA III	
FIELD 06	GROUP 04		
06	05		
19. ABSTRACT (Continue on reverse if necessary and identify by block number) We have, more precisely than ever before, defined the mechanical limitations to normal exercise in healthy persons. In most instances in the normal or moderately fit individual the ventilatory requirement is such that mechanical limitations are barely reached on expiration, but not to inspiratory muscles in heavy exercise and fatigue of respiratory muscles is not a factor. The greater the level of physical fitness, the greater the maximum exercise load the greater the probability that mechanical limitation to flow on expiration and to pressure generation by inspiratory muscles on inspiration will be achieved over a substantial part of the tidal breath. This results in an even higher oxygen cost of respiration in these subjects that reach mechanical limitation. On the other hand, it is only in very rare instances that we observed that this mechanical limitation interfered with the provision of sufficient alveolar hyperventilation in these subjects to achieve adequate gas exchange and arterial oxygenation and acid-base regulation.			
20. DISTRIBUTION/AVAILABILITY OF ABSTRACT <input type="checkbox"/> UNCLASSIFIED/UNLIMITED <input type="checkbox"/> SAME AS RPT <input type="checkbox"/> DTIC USERS		21. ABSTRACT SECURITY CLASSIFICATION Unclassified	
22a. NAME OF RESPONSIBLE INDIVIDUAL Mrs. Virginia M. Miller		22b. TELEPHONE (Include Area Code) (301) 663-7325	22c. OFFICE SYMBOL SGRD-RMI-S

FOREWORD

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Introduction. The studies we are currently undertaking, and that were proposed in the original contract application, are concerned with mechanical limitations to breathing in heavy exercise, in normoxia and hypoxia. Most previous work on this topic gave rise to the concept that ventilation in heavy exercise never achieved mechanical limits, and that either the limitation to this ventilation, or its cost, would rarely if ever be a factor in the limitation of physical performance. Our previous studies, on the other hand, have indicated that indeed the gas exchange function of the lung can fail in very heavy exercise, and that in some instances, very fit persons may play a major role in limiting their oxygen transport and CO₂ transport, and acid base regulation. Thus it was our specific goal here to study the metabolic cost of breathing and to find whether mechanical limits to ventilation were indeed ever achieved in heavy exercise, in normoxia and hypoxia.

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Body. The Methods we used were adaptations of established techniques and included:
a) the definition of limitations to expiratory flow as determined in a body plethysmograph,
b) definition of the limitations to pressure development by the inspiratory muscles, c)
measurement of dynamically determined end-expiratory lung volume (FRC) and the flow
volume and pressure volume profile of tidal breathing in heavy exercise. These techniques
were used to define the mechanical limits to inspiration and expiration. We then applied
these to normal, healthy males of widely varying fitness levels as they exercised progressively
to maximum short-term exercise. Thus far we have obtained the following major findings:

- 1) In most healthy young adults studied, we found very efficient regulation
of the lung and chest wall mechanics. For example, progressive exercise saw
a progressively reduced and expiratory lung volume, which is accomplished
with active expiration. This meant that the inspiratory muscles, including the
diaphragm, were placed at a much longer length for the subsequent
inspiration and were thus able to develop considerable tension to reach the
high tidal volumes recorded in heavy exercise. In moderately fit individuals,
some limitation to expiratory flow was usually reached. But this only occurred
at the very extreme exercise levels, and at very low lung volumes. The
capacity of inspiratory muscles to develop pressure decreased with increasing
flow rate (velocity of shortening) and with increasing lung volume during
progressive exercise; but the peak inspiratory pressure actually achieved
during exercise rarely exceeded 50% of the capacity of the inspiratory muscles
to generate pressure.

- 2) We determined the oxygen cost of exercise ventilation by having the subjects mimic (at rest) the actual work breathing that they accomplished during sub maximal or maximal exercise. At maximal exercise, the oxygen cost of respiration averaged 10% of the total body VO₂. In some subjects, ie, especially those who approached expiratory and low inspiratory flow limitation in very heavy exercise, the oxygen cost of ventilation reached 13-15% of maximal oxygen consumption.
- 3) Fatigue of the respiratory muscles was not evident in these subjects as they were able to continue the work of breathing they experienced during exercise for three to ten times longer (at rest) than the exercise period itself.
- 4) A fitter group of subjects, ie, endurance athletes, all showed substantial limitation to expiratory flow and to pressure generation by inspiratory muscles at maximum exercise. That these subjects had reached the capacity for flow generation during expiration on the one hand, and pressure generation by the inspiratory muscles on the other, was demonstrated by superimposing a CO₂ load for them to breathe at maximum exercise. This showed that their minute ventilation was unable to rise any higher, nor was their pressure or flow:volume loop enlarged beyond that obtained during maximum exercise air breathing.

Conclusions. We have, more precisely than ever before, defined the mechanical limitations to normal exercise in healthy persons. In most instances in the normal or moderately fit individual, the ventilatory requirement is such that mechanical limitations are barely reached on expiration, but not to inspiratory muscles in heavy exercise and fatigue of respiratory muscles is not a factor. On the other hand, the oxygen cost of ventilation may be quite high, even in these subjects who do not reach limitation, ie, 10-15% of the total body O₂ cost which would represent a substantial potential "steal" of blood flow and oxygen consumption from locomotor muscles.

Conclusion II. The greater the level of physical fitness, the greater the maximum exercise load achieved, the greater the probability that mechanical limitation to flow on expiration and to pressure generation by inspiratory muscles on inspiration will be achieved over a substantial part of the tidal breath. This results in an even higher oxygen cost of respiration in these subjects that reach mechanical limitation. On the other hand, it is only in very rare instances that we observed that this mechanical limitation interfered with the provision of sufficient alvelor hyperventilation in these subjects to achieve adequate gas exchange and arterial oxygenation and acid-base regulation.

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